GPUs: Engines for Future High-Performance Computing

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GPUs as Compute Engines

10 years ago:

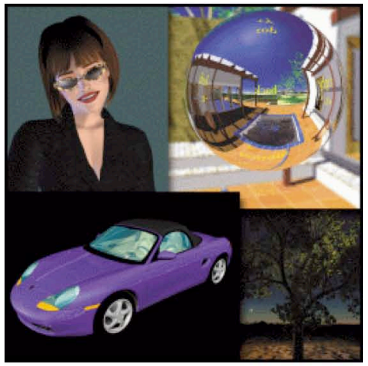
- Graphics done in software

5 years ago:

- Full graphics pipeline

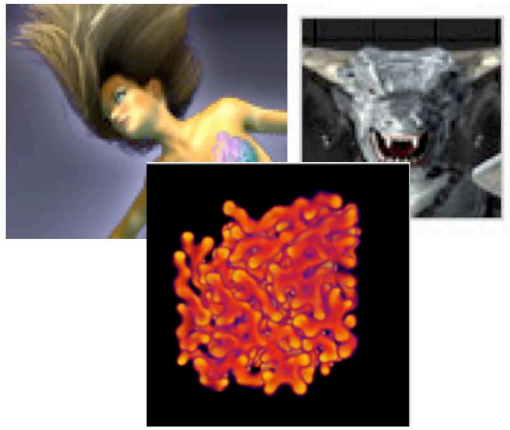
Today:

- 40x geometry, 13x fill vs. 5 yrs ago
- Programmable!

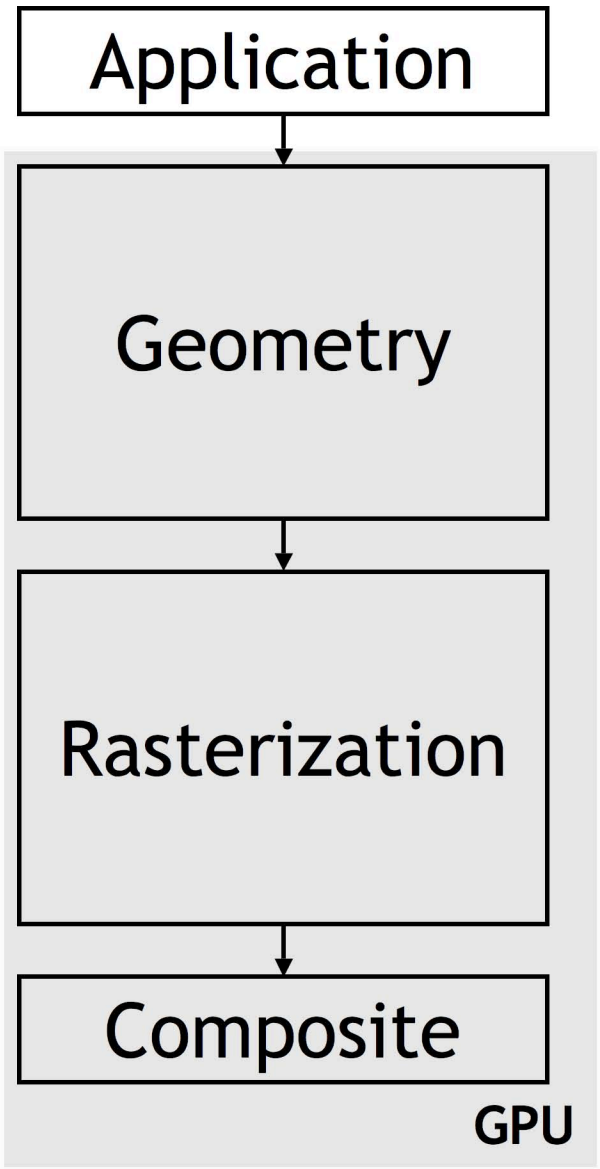


Programmable, data parallel processing on every desktop

Enormous opportunity to change the way commodity computing is done!



The Rendering Pipeline



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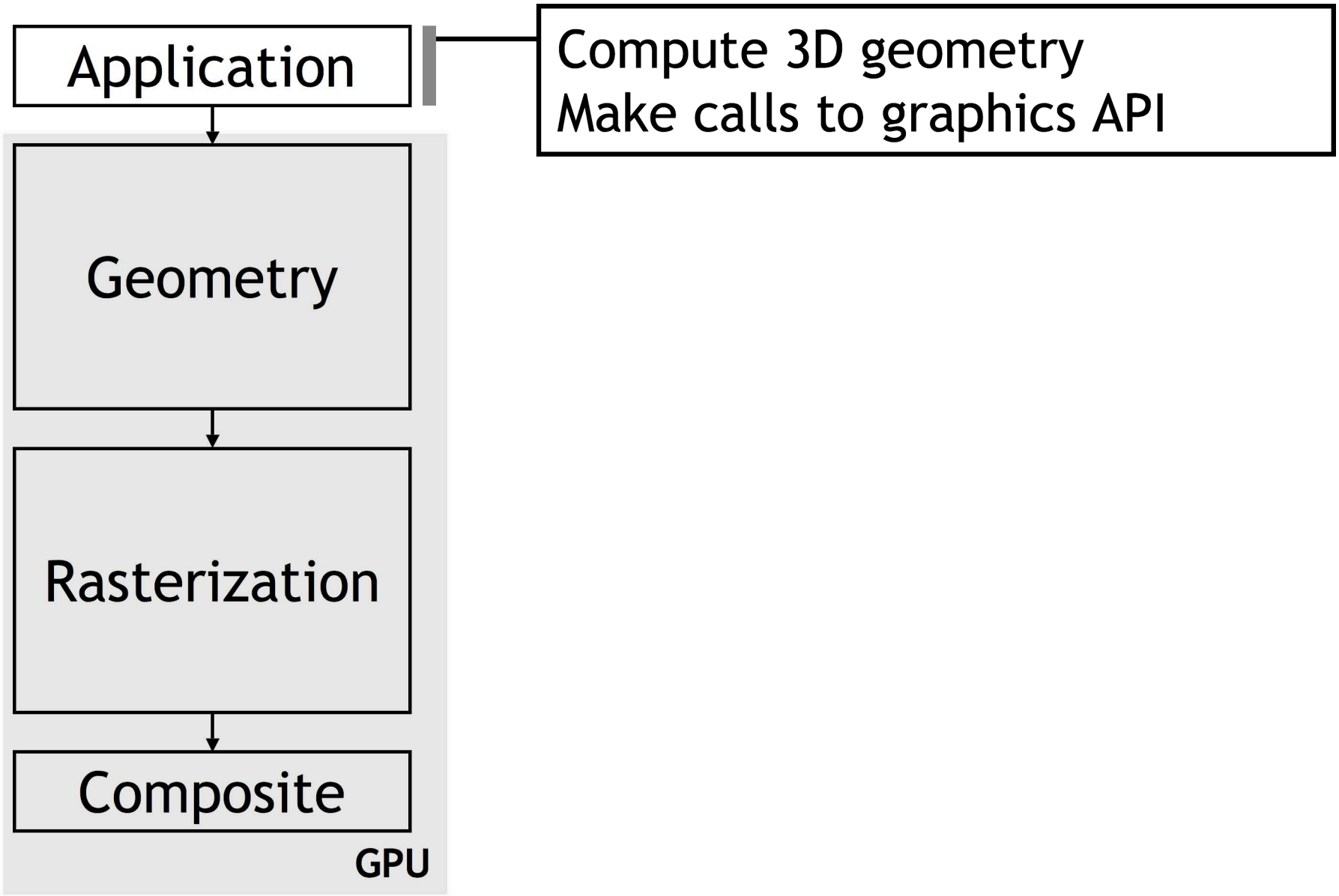

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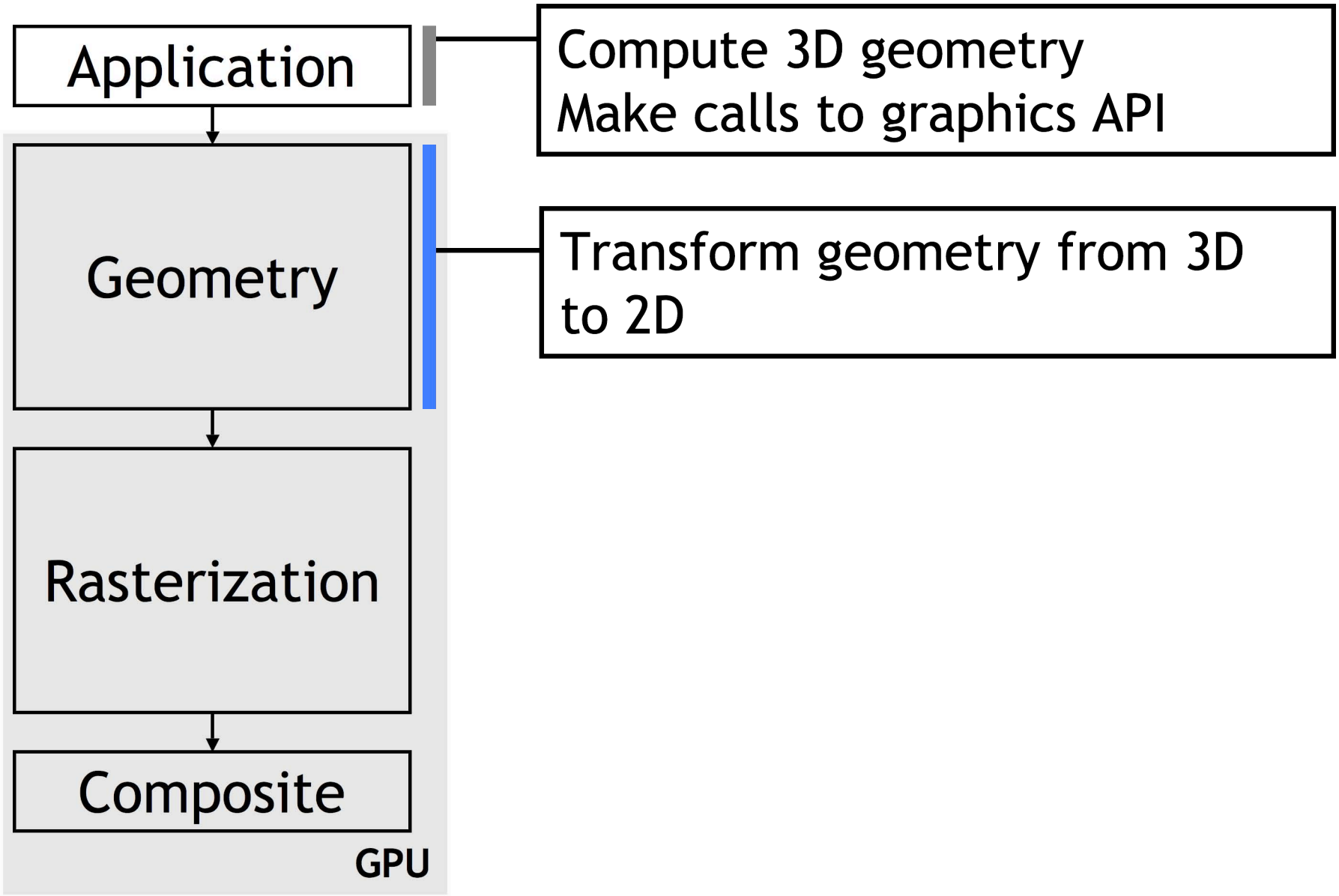

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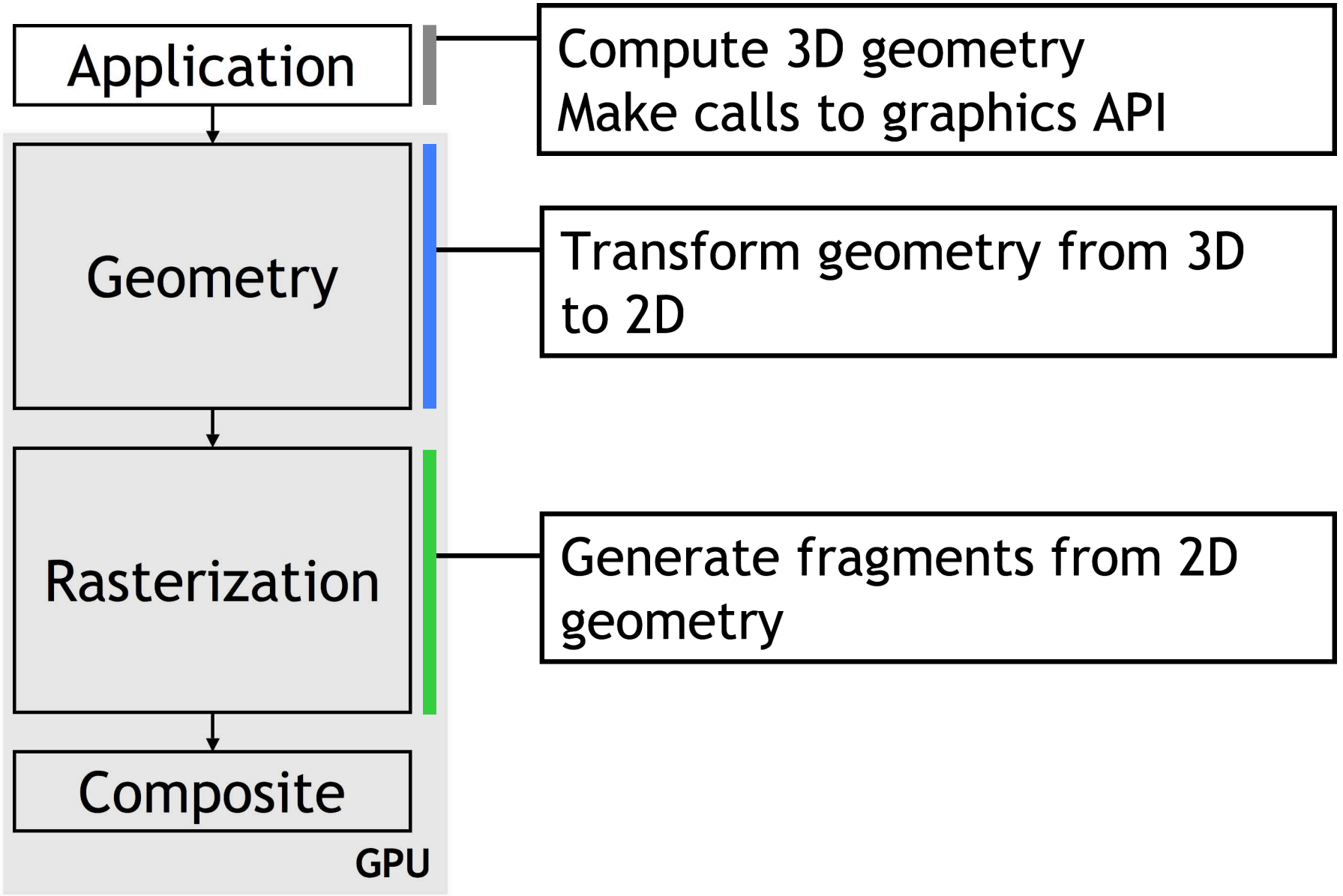

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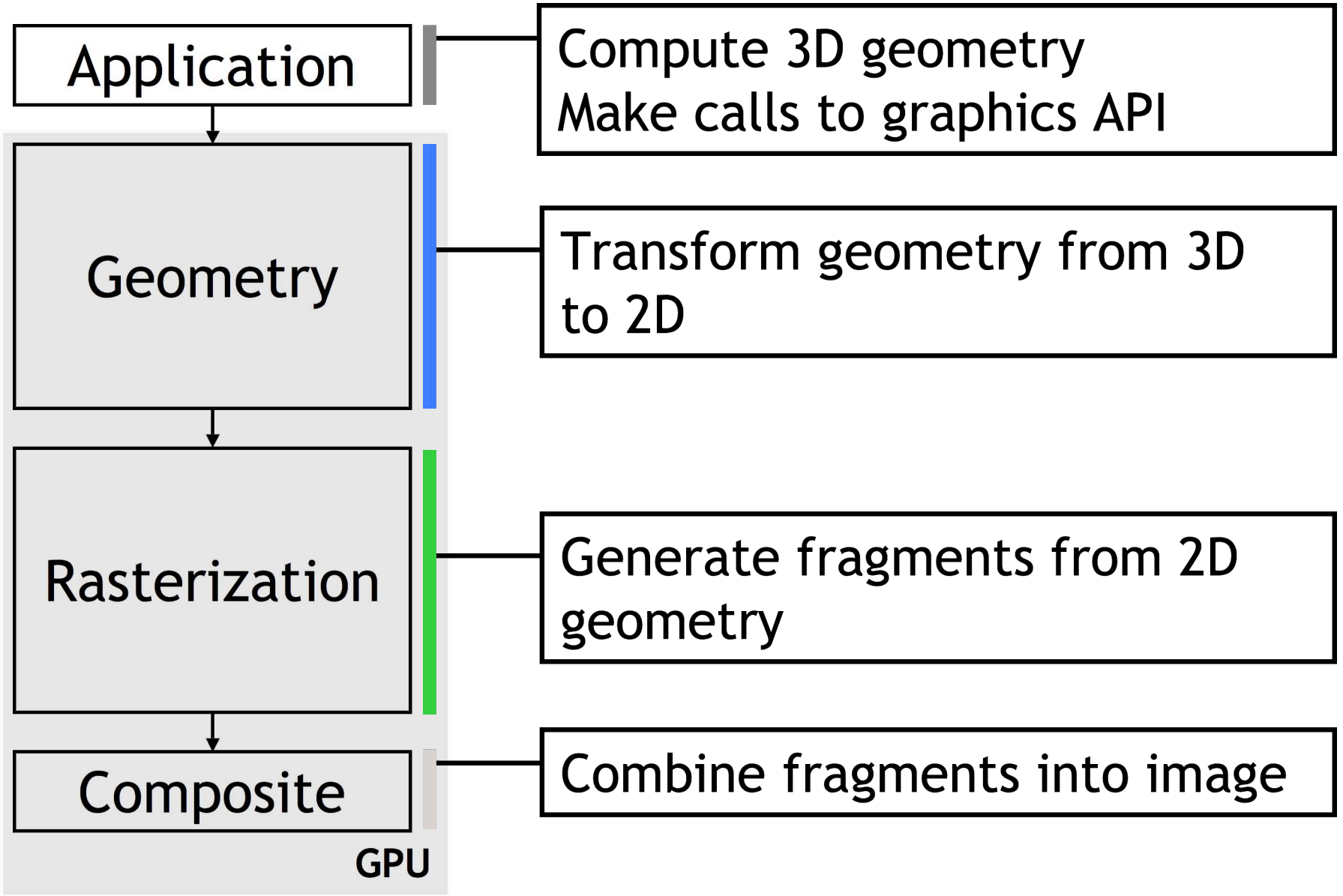
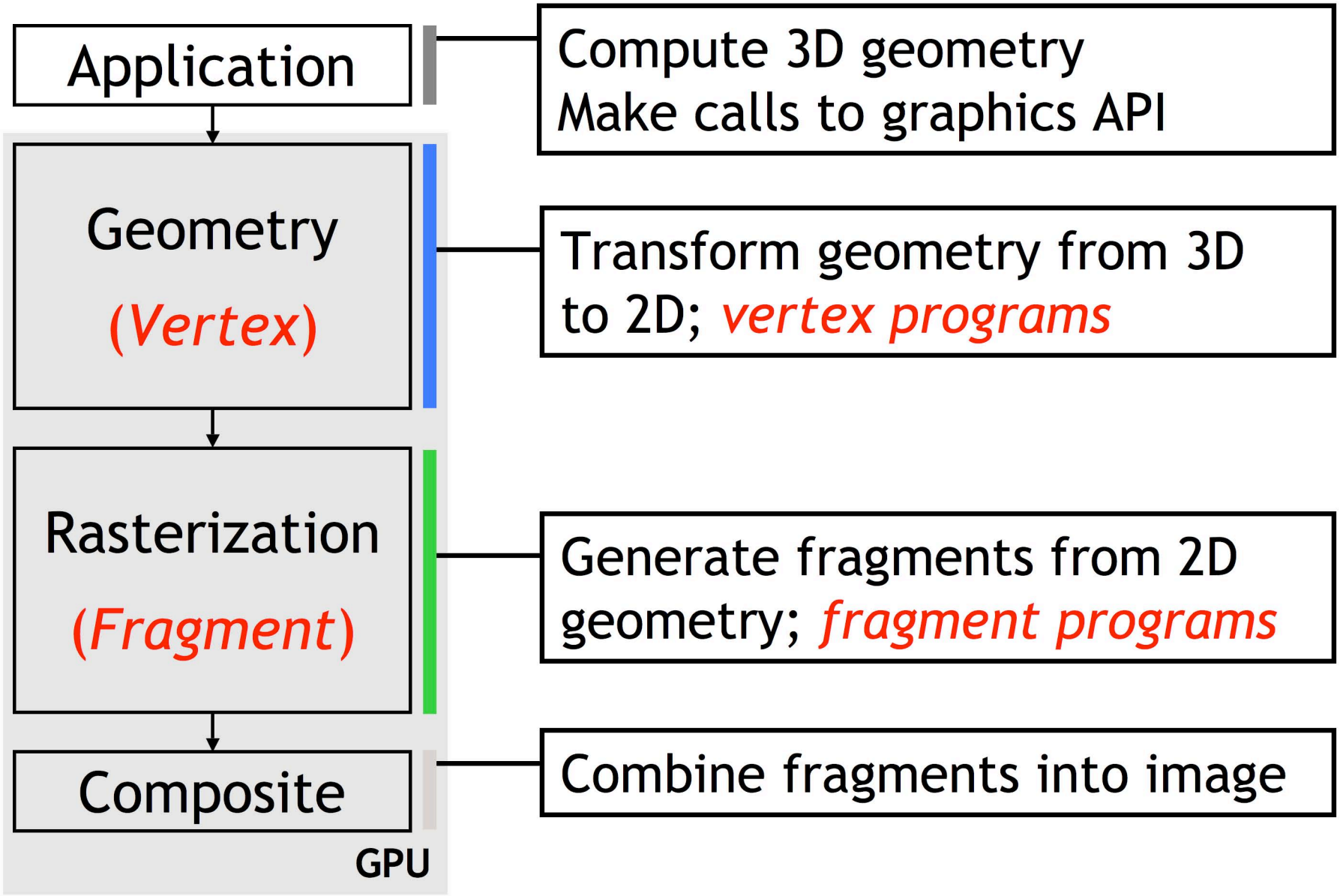
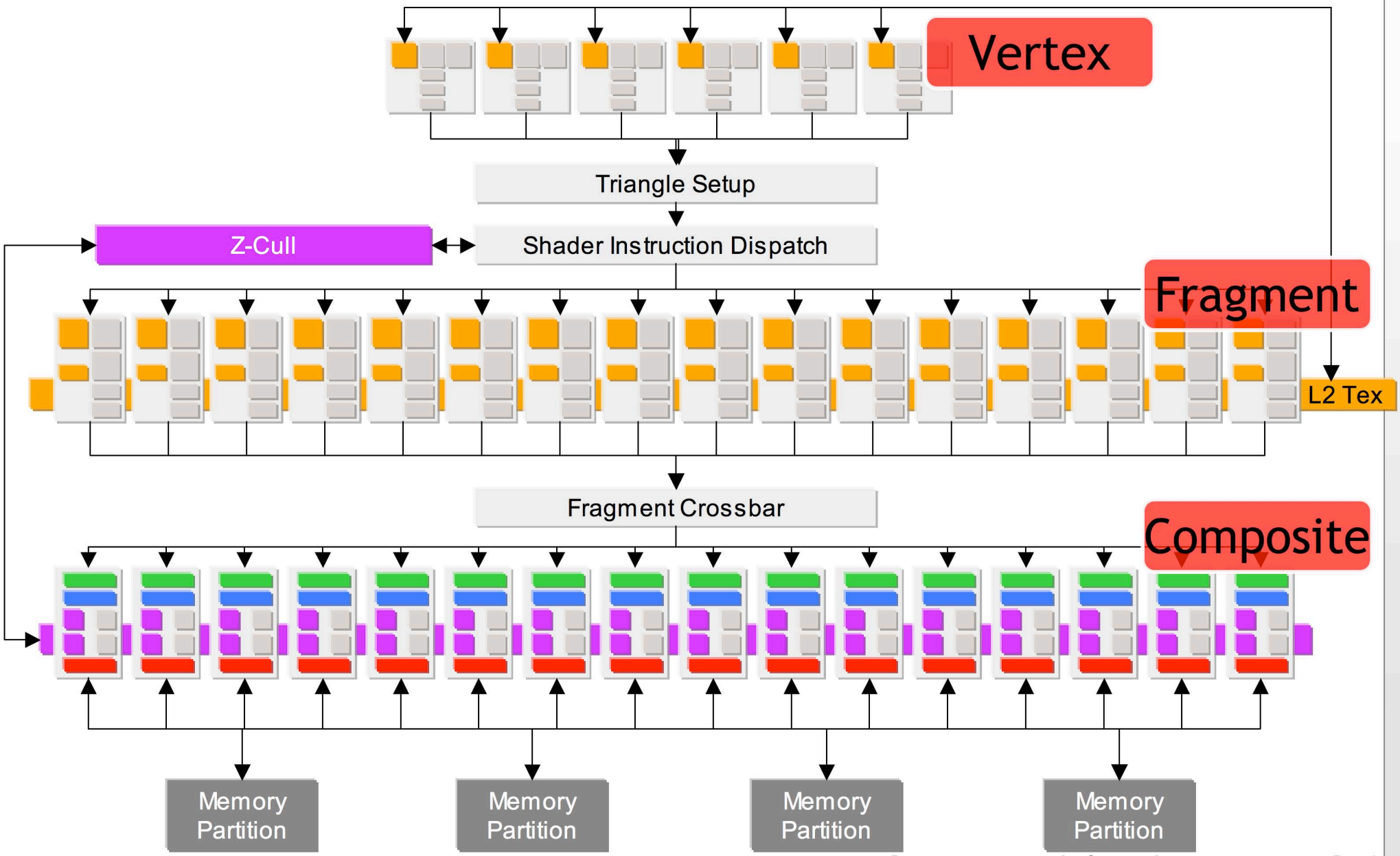


The Programmable Rendering Pipeline

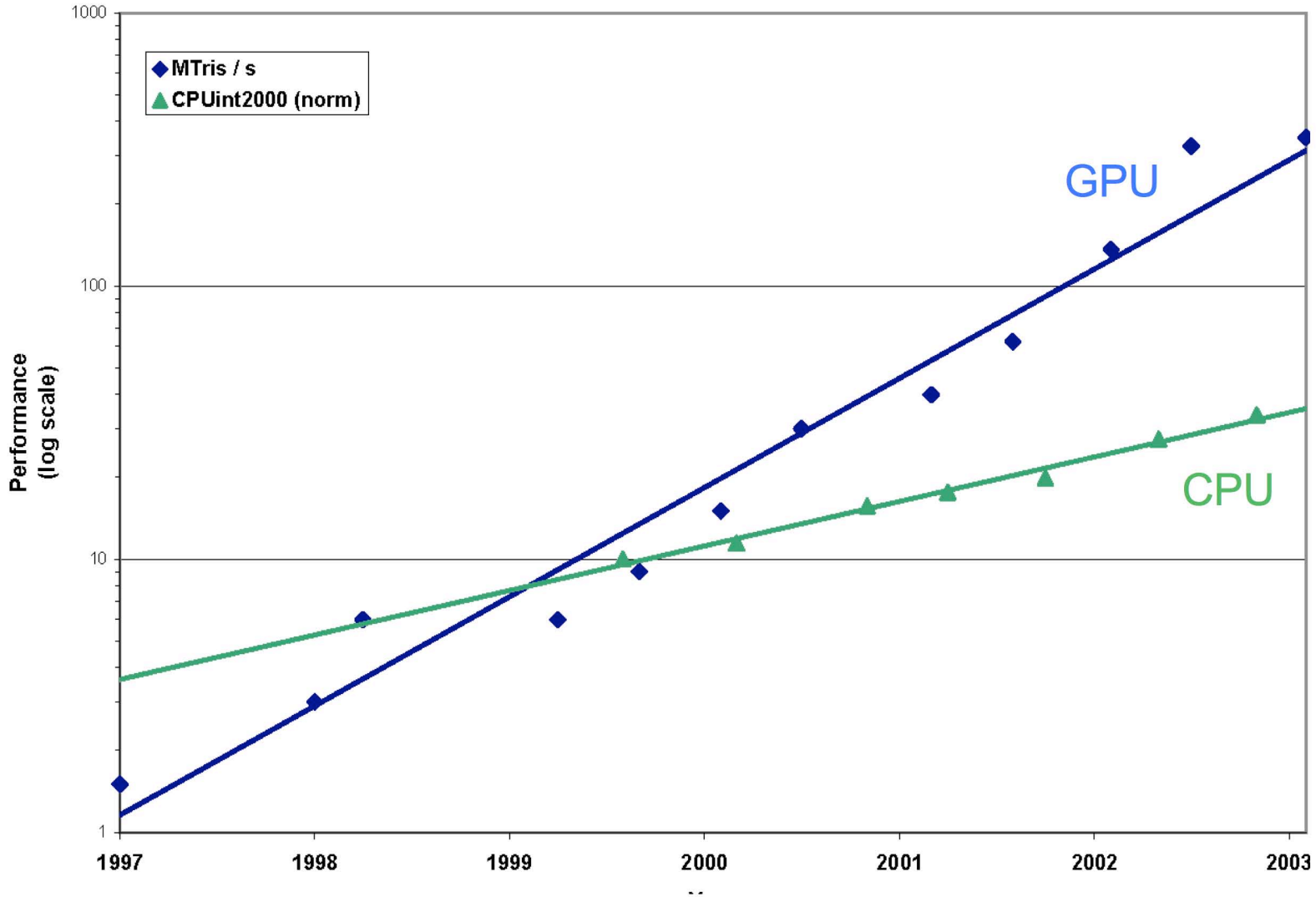


NVIDIA GeForce 6800 3D Pipeline



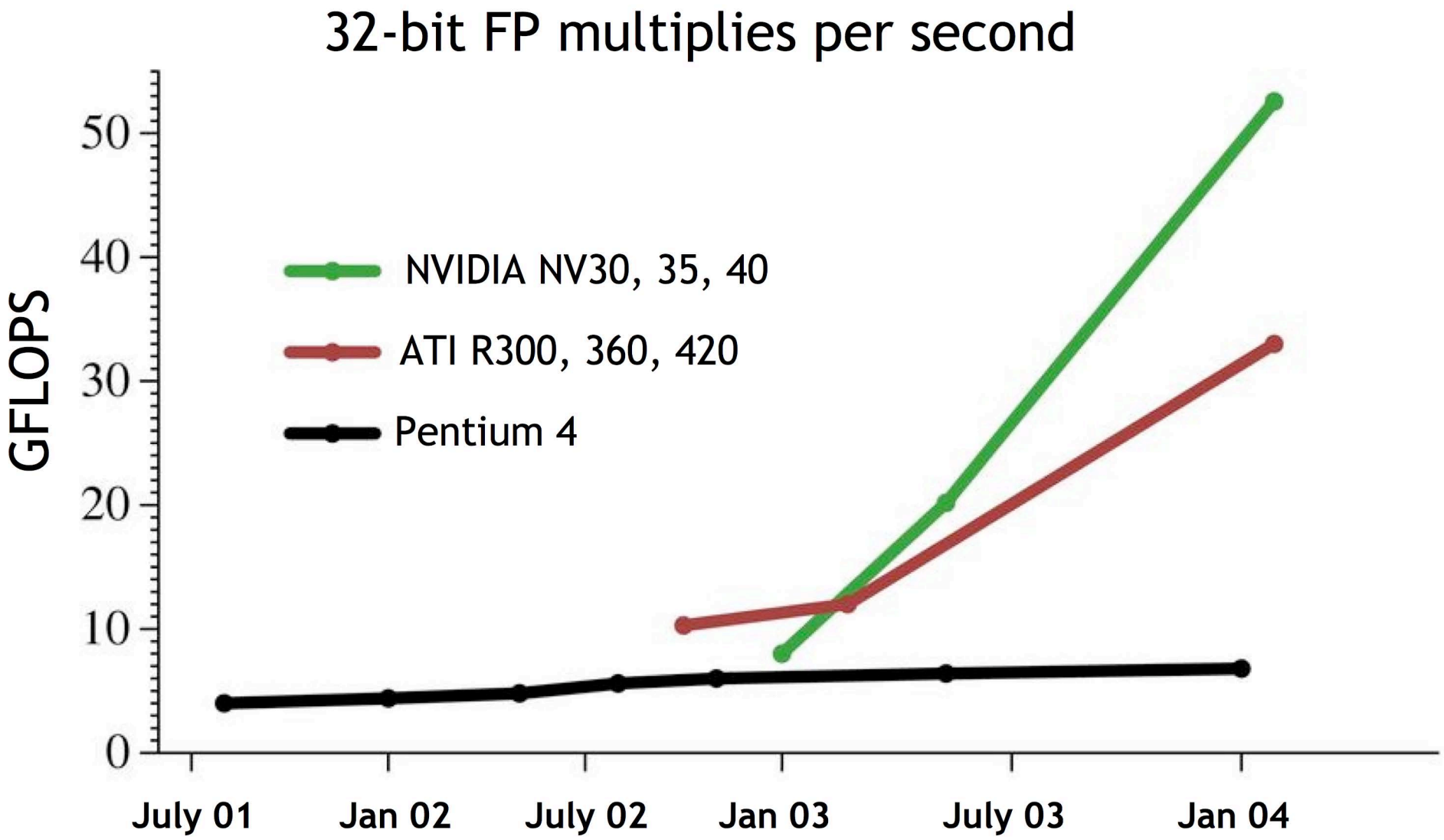
Courtesy Nick Triantos, NVIDIA

Long-Term Trend: CPU vs. GPU



Courtesy Naga Govindaraju

Recent GPU Performance Trends



Courtesy Pat Hanrahan/David Luebke

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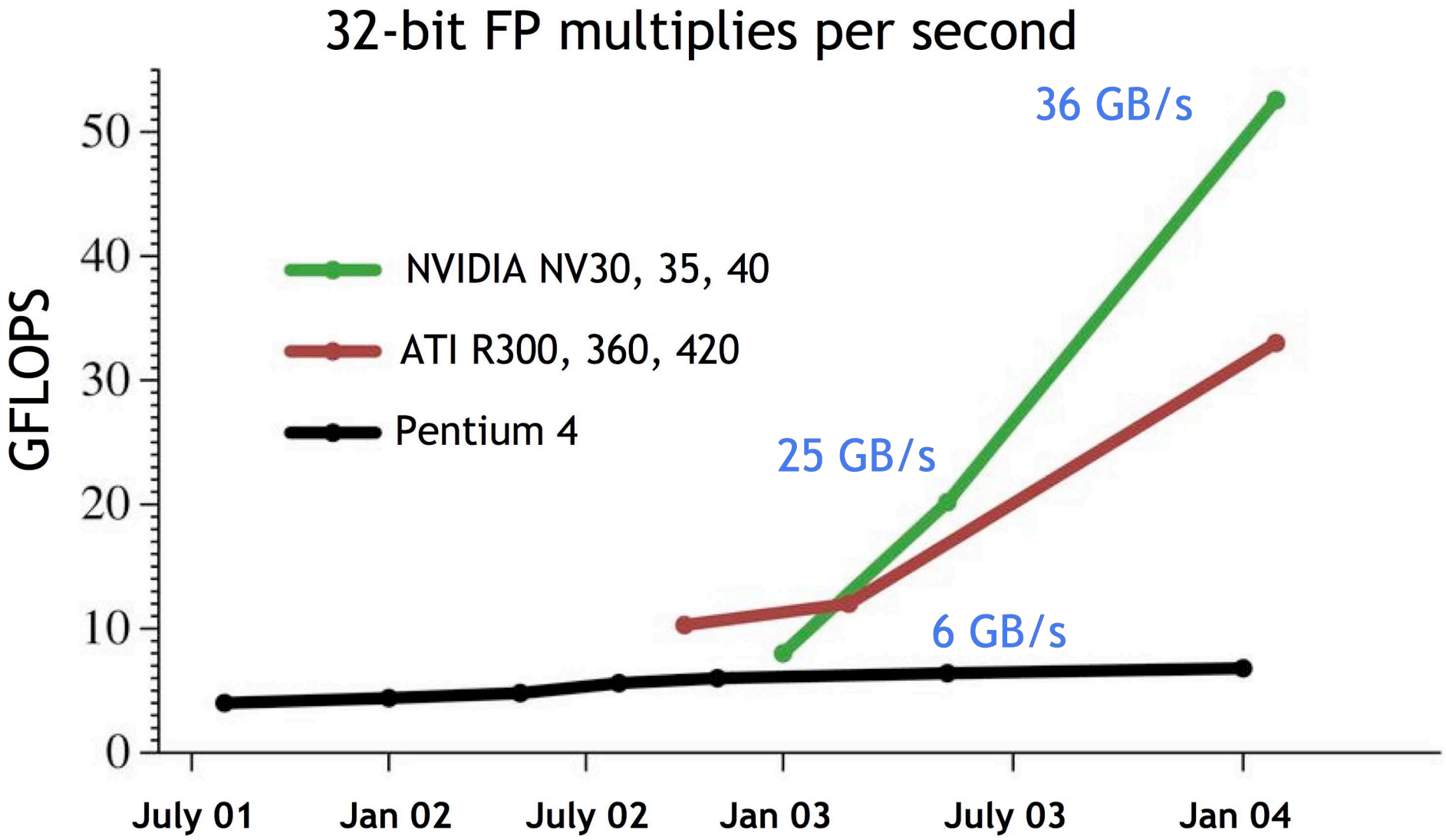

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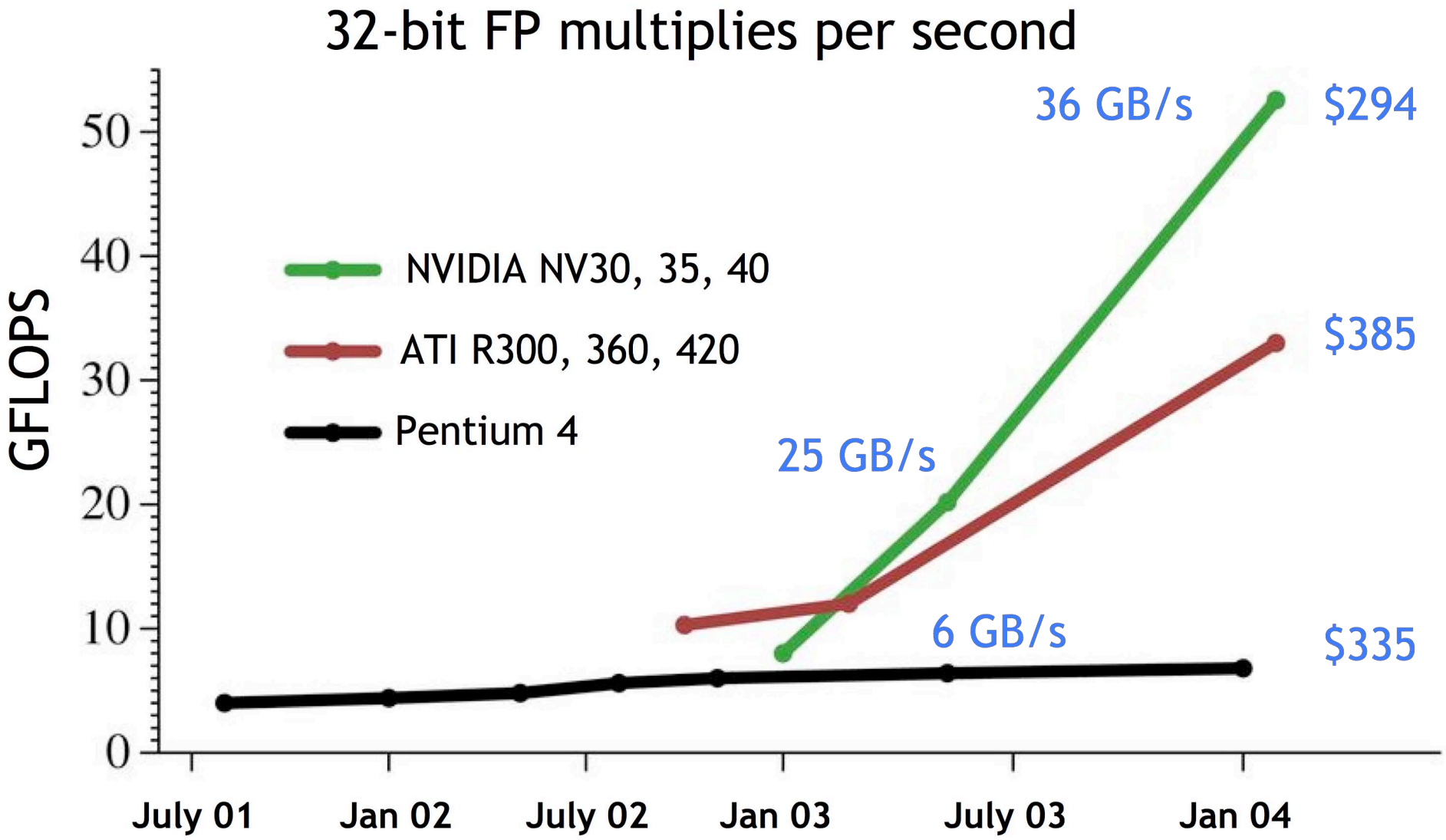


Courtesy Pat Hanrahan/David Luebke

Why Are GPUs Fast?

Characteristics of computation permit efficient hardware implementations

- High amount of parallelism …
- … exploited by graphics hardware
- High latency tolerance and feed-forward dataflow …
- … allow very deep pipelines
- … allow optimization for bandwidth not latency

Simple control

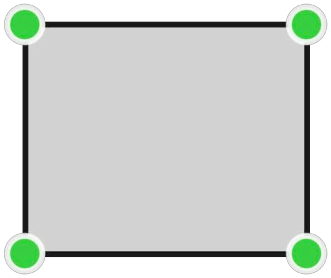
- Restrictive programming model

Competition between vendors

What about programmability? Effect on performance? How hard to program?

Programming a GPU for GP Programs

Programming a GPU for GP Programs



- Draw a screen-sized quad

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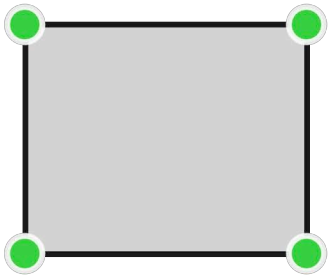

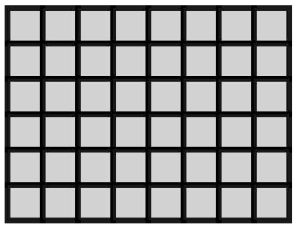

- Draw a screen-sized quad
- Run a SIMD program over each fragment

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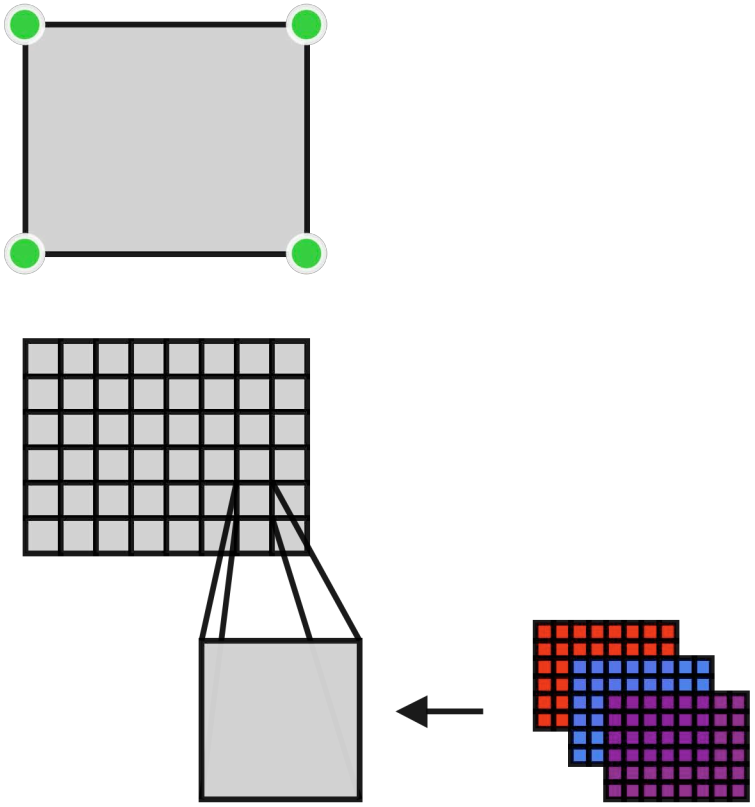

- Draw a screen-sized quad
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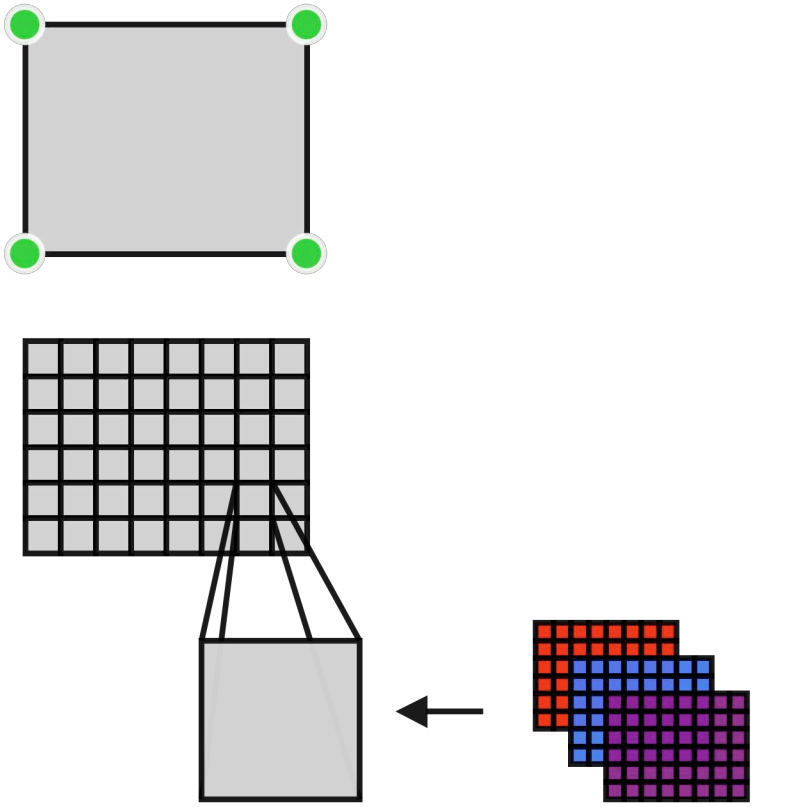
- "Gather" is permitted from texture memory

Programming a GPU for GP Programs

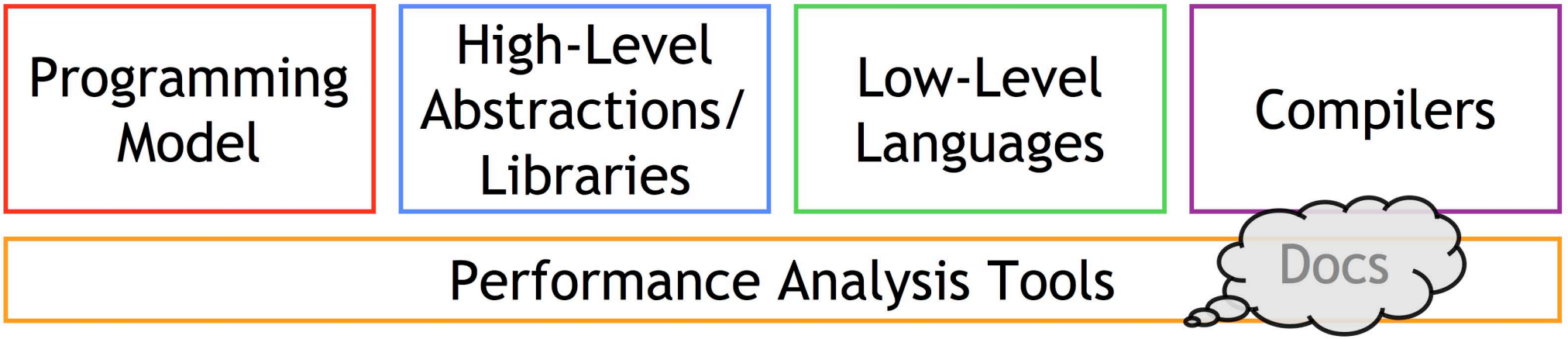


- Draw a screen-sized quad
- Run a SIMD program over each fragment
- "Gather" is permitted from texture memory
- Resulting buffer can be treated as texture on next pass

GPU Programming is Hard

- Must think in graphics metaphors
- Requires parallel programming (CPU-GPU, task, data, instruction)
- Restrictive programming models and instruction sets
- Primitive tools
- Rapidly changing interfaces

Challenge: Programming Systems



CPU	GPU
Scalar	Stream?
STL, GNU SL, MPI, …	-
C, Fortran, …	GLSL, Cg, HLSL, …
gcc, vendor-specific, …	Vendor-specific
gdb, vtune, Purify, …	Shadesmith, NVPerfHUD
Lots	None
→ *applications*	→ *kernels*

Brook: General-Purpose Streaming Language

Stream programming model

- Treats GPU as streaming coprocessor
- Streams enforce data parallel computing
- Kernels encourage arithmetic intensity
- Streams and kernels explicitly specified

C with stream extensions

Open-source: www.sf.net/projects/brook/

Ian Buck et al., "Brook for GPUs: Stream Computing on Graphics Hardware", Siggraph 2004

Challenge: GPU-to-Host Bandwidth

GPUs lack band-width to the host, so we won't use it!

No one uses host bandwidth, so we won't optimize it!

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No one uses host bandwidth, so we won't optimize it!

- **PCI-E optimizes GPU-to-CPU bandwidth**
  - 16-lane card: 8 GB/s
  - Scalable in future
- **Major vendors support PCI-E cards now**
- **Multiple GPUs supported per CPU - opportunity!**
  - Cheap and upgradable

Challenge: Mobile/embedded market

Why?

- UI, messaging/screen savers, navigation, gaming (location based)

POWERVR
Visionary IP

Typical specs (cell-phone class):

- 200-800k gates, ~100 MHz, ~100 mW
- 1-10M vtx/s, 100+M frags/s

NVIDIA
GeForce 3D
4500

Z3D
Graphics
Engine

What's important?

- Visual quality
- Power-efficient (ops/W)
  - Avoid memory accesses, unified shaders …
- Low cost

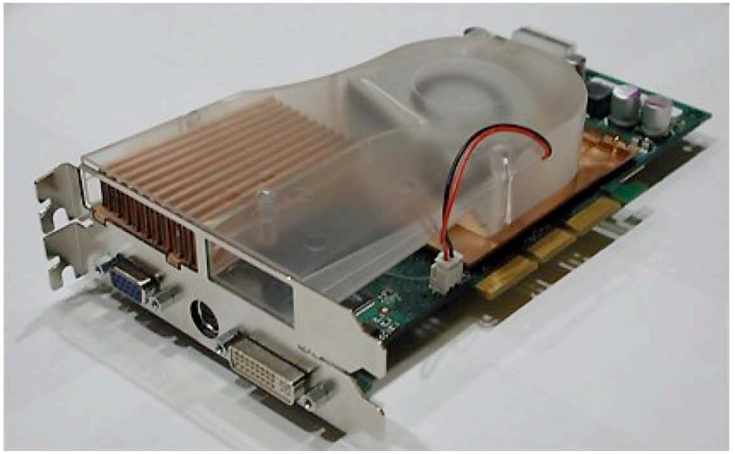
FALANX
microsystems

BITBOYS

Challenge: Power

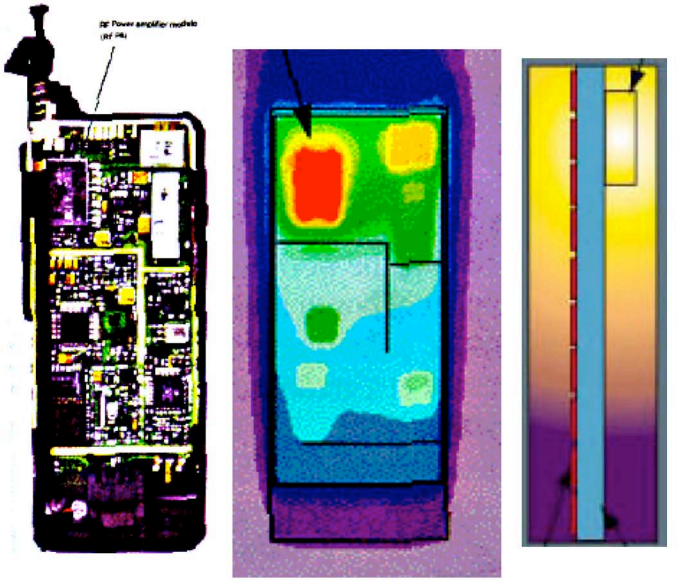
Desktop:

- Double-width cards
- Workstation power supplies; draw power from motherboard



Mobile:

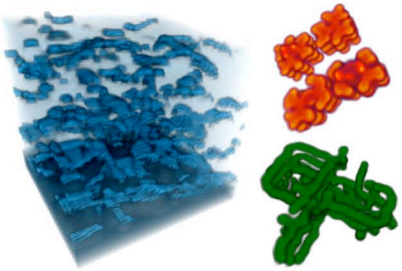
- Batteries improving 5-10% per year
- Ops/W most important

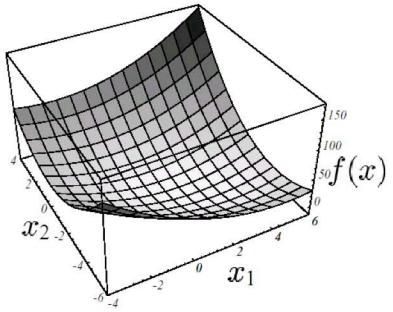


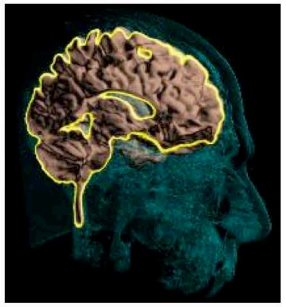
www.coolingzone.com

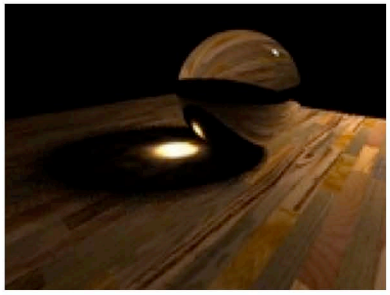
Current GPGPU Research

- Image processing [Johnson/Frank/Vaidya, LLNL]
- Alternate graphics pipelines [Purcell, Carr, Coombe]
- Visual simulation [Harris]
- Volume rendering [Kniss, Krüger]
- Level set computation [Lefohn, Strzodka]
- Numerical methods [Bolz, Krüger, Strzodka]
- Molecular dynamics [Buck]
- Databases [Sun, Govindaraju]
- …









Grand Challenges

Architecture: Increase features and performance without sacrificing core mission

Interfaces: Abstractions, APIs, programming models, languages

- *Many* approaches needed
- Goal: C programs compiling to dynamically-balanced CPU-GPU clusters
- Academic and research community

Applications: Killer app needed!

Acknowledgements

Craig Lund: Mercury Computer Systems

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Mark Segal: ATI

Kari Pulli: Nokia

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Ian Buck: Stanford

Funding: DOE Office of Science, Los Alamos National Laboratory, ChevronTexaco, UC MICRO, UC Davis

For more information …

GPGPU home: http://www.gpgpu.org/

- Mark Harris, UNC/NVIDIA

GPU Gems (Addison-Wesley)

- Vol 1: 2004; Vol 2: 2005

Conferences: Siggraph, Graphics Hardware, GP^2

- Course notes: Siggraph ‘04, IEEE Visualization ‘04

University research: Caltech, CMU, Duisberg, Illinois, Purdue, Stanford, SUNY Stonybrook, Texas, TU München, Utah, UBC, UC Davis, UNC, Virginia, Waterloo